ANALYSIS OF MATERIALS IN CLIFF AND BARN SWALLOW NESTS: RELATIONSHIP BETWEEN MUD SELECTION AND NEST ARCHITECTURE

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Studies of the mud nests of Cliff (*Petrochelidon pyrrhonota*) and Barn swallows (*Hirundo rustica*) have heretofore emphasized nest-site selection and nest-building activity (e.g., Emlen 1952, 1954, Mayhew 1958, Samuel 1971, Jackson and Burchfield 1975). While it is usually acknowledged in these studies that a "proper consistency of mud" is essential for nest construction, there are no specific data available on the actual texture or consistency of such materials. Furthermore, it is not known if or how the design of nests constructed by these species may affect the selection of building materials; Cliff Swallows build nests which are enclosed and retort-shaped, whereas Barn Swallows construct simple cup-shaped nests (Samuel 1971). The purposes of this study were to analyze the materials used by these swallows in nest construction and to determine if there are interspecific differences which may be related to nest construction or design.

MATERIALS AND METHODS

Collecting sites.—Three Cliff and 3 Barn swallow nests were collected at each of 11 sites in western Montana (Fig. 1). At 7 of these sites (1, 3, 4, 8, 9, 10, 11), nests of both species were found within a few meters of each other on the same structure (concrete or wooden bridge, barn, or highway overpass). At the remaining 4 sites, nests of both species were located on different structures, but were never more than 400 m apart.

Analyses.—Samples of each nest were analyzed for texture (% sand, % silt, % clay), sand size, organic matter, and water content. Texture refers to the type and relative numbers of particles in the sample (Baver et al. 1972).

Two 50 g samples of dried mud from each nest were analyzed for texture by the hydrometer method described by Bouyoucos (1936). In intact nests (5 Cliff, 7 Barn) 1 sample was taken from the area of attachment (base), while the other was selected from the rim or opening of the nest. In other nests, the samples were not selected from specific regions. Because the amount and kind of organic matter in the samples varied considerably, they were not routinely treated with hydrogen peroxide. Instead, conspicuous pieces of organic matter were removed by hand.

The suspension remaining after the textural analysis was washed through 4 brass sieves, sizes 20, 32, 60, and 120. The mesh openings of these sieves are 0.841, 0.557, 0.250, and 0.125 mm, respectively. The portions of the suspension which were retained in the sieves were air dried and weighed on a semi-microbalance. Non-sand materials were eliminated from the residue before weighing. Sand remaining in the size 20 sieve was classified as very coarse sand, that in the size 32 sieve as coarse sand, that in the size 60 sieve as medium sand, and that in the size 120 sieve as fine sand (USDA 1951).

An additional 15 g sample from each nest was air dried at 110°C for 24 h and then

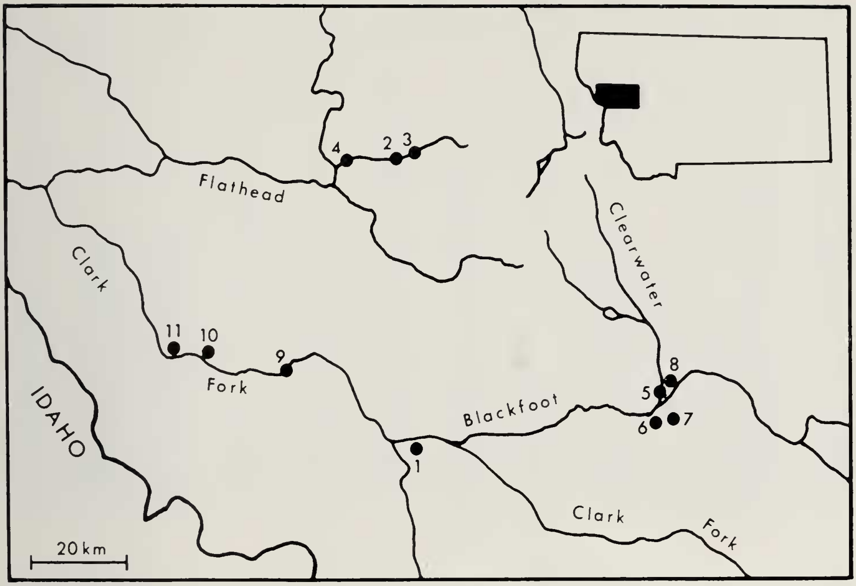

FIG. 1. Distribution of collecting sites in western Montana.

ignited at 400°C for 7 h. This procedure yielded information on water content and organic matter in the dried mud sample (Jackson 1958). These values for water content were used in the calculations of textural components.

The amount of material in each textural category, the amount of organic matter, and the water content of each sample are expressed as percentages of the total weight of the sample, while the amount of sand in each size category is expressed as a percentage of the total weight of sand in the sample.

Statistical treatment of data.—Variation between species, among sites, among nests within each site, and within individual nests in each textural and sand size category was analyzed with a mixed-model 2 factor analysis of variance (ANOVA) with 2 levels of nesting. Variation between species and among sites in water content and organic matter was analyzed with a mixed-model 2 factor ANOVA (Sokal and Rohlf 1969). Differences between samples taken from the rim and base in textural components and sand size were analyzed with *t*-tests.

All percentages were transformed to angles (arcsine transformation) prior to analysis with ANOVA or *t*-test (Sokal and Rohlf 1969).

RESULTS

Textural components.—The soil-like material in the nests of both swallows was predominantly sand, with modest amounts of silt and some clay (Fig. 2). Sand particles comprised 61.4 ± 0.8% and 56.4 ± 1.1% of the mud samples from Cliff and Barn swallow nests, respectively, while silt particles accounted

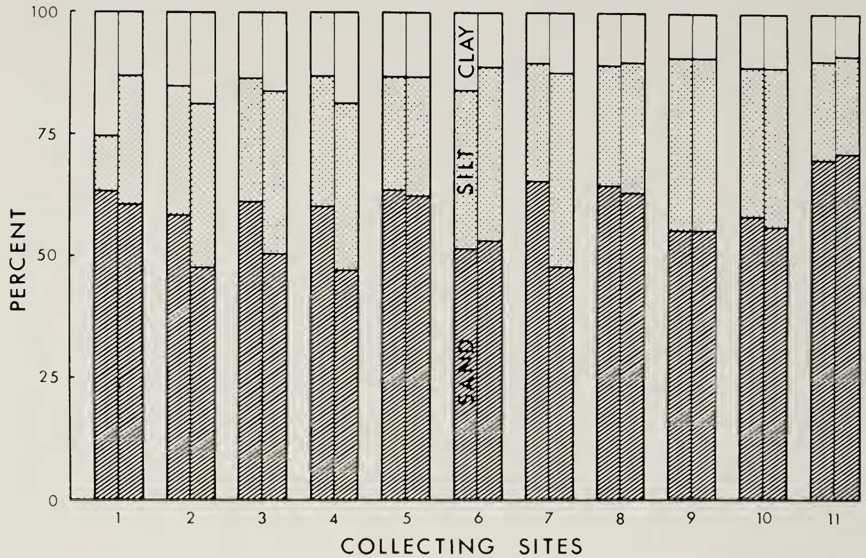

FIG. 2. Textural components of mud samples from Cliff (left half) and Barn swallow (right half) nests at all 11 collecting sites. Values are mean percentages for each component.

for 25.7 ± 0.9% and 31.5 ± 0.9% (values are means ± SE). The mean amount of clay in the mud samples was similar for both species, 12.7 ± 0.7% and 11.9 ± 0.6%, respectively.

At most localities (8 of 11), the mud in Cliff Swallow nests contained more sand and fewer silt particles than that from Barn Swallow nests (Fig. 2). These species differences in sand and silt content are statistically significant ($P < .05$), as are the differences in clay content ($P < .05$). However, the interspecific differences in clay content are more dependent on the locality, yet there is no recognizable trend among sites (Fig. 2). Cliff Swallows at 4 sites used mud with a greater clay content than that selected by Barn Swallows, while at 4 other localities the reverse was true. The variations in texture among nests within a site and among collecting sites are likewise statistically significant ($P < .05$). Intra-site variation accounts for 21%, 15.9%, and 17.8% of the total variation in percent sand, silt, and clay, respectively, while the variation among sites accounts for 47.3%, 49.9%, and 46%.

Sand size.—The sand particles in the mud samples from the nests of both species was mostly of a small size (Fig. 3). In Cliff Swallow nests, 41.0 ± 2.2% of the sand was fine, 27.8 ± 1.3% was of medium size, 9.3 ± 0.6% was coarse, and 21.9 ± 2.0% was of very coarse size (values are means ± SE).

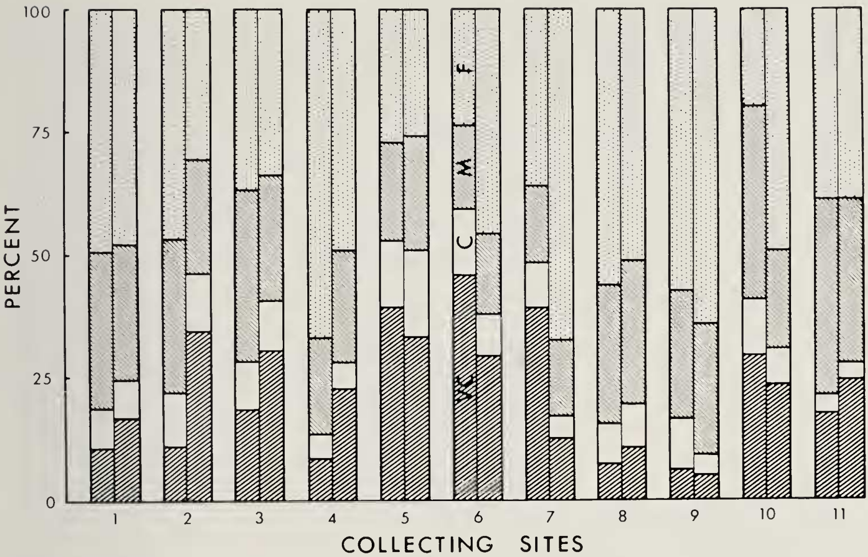

FIG. 3. Distribution of sand sizes in mud samples from Cliff (left half) and Barn swallow (right half) nests at all 11 collecting sites. VC represents the proportion of very coarse sand, C the percentage of coarse sand, M the proportion of medium sand, and F the percentage of fine sand. Values are mean percentages for each component.

The corresponding values in Barn Swallow nests were 44.9 ± 2.5%, 23.8 ± 0.9%, 8.0 ± 0.6%, and 21.7 ± 1.9%, respectively.

The amount of sand in each of these size categories varied widely among collecting sites and nests at a particular site and between species (Fig. 3). The 2 species appeared to be selecting mud with different amounts of sand in each of these categories, but these species differences were not the same at most sites (Fig. 3). The amount of sand of a specific size occurring in the mud samples was primarily dependent on the locality. Variation in the amount of sand in these size categories among nests within a site and among sites is statistically significant ($P < .05$). Variation within a site accounts for 25.7 to 36% of the total variation in all size categories, while variation among localities accounts for 35.6 to 47.7%.

Organic matter.—There was a moderate amount of organic matter in the mud of all Cliff and Barn swallow nests, although the actual amount and form of the organic matter varied with the species (Table 1). Organic matter accounted for a mean of 6.6 ± 0.5% of the samples from Barn Swallow nests, but only 4.5 ± 0.4% of samples from the nests of Cliff Swallows. This difference is statistically significant, as are the differences among collecting

TABLE 1

ORGANIC MATTER AND MOISTURE CONTENT IN MUD SAMPLES FROM CLIFF AND BARN SWALLOW NESTS

Collecting sites	Organic matter		Moisture content	
	Cliff	Barn	Cliff	Barn
1	3.2 ± 0.2[a]	7.5 ± 1.7	1.8 ± 0.1	1.9 ± 0.3
2	6.7 ± 0.7	8.5 ± 1.1	2.5 ± 0.2	3.5 ± 0.9
3	4.3 ± 0.7	8.0 ± 0.8	1.4 ± 0.1	2.0 ± 0.2
4	1.1 ± 0.2	5.2 ± 0.5	3.4 ± 1.6	1.3 ± 0.1
5	6.2 ± 1.1	5.6 ± 1.2	1.7 ± 0.4	1.8 ± 0.3
6	9.5 ± 1.3	5.2 ± 1.8	3.5 ± 0.6	1.6 ± 0.4
7	2.7 ± 0.2	4.8 ± 0.9	1.2 ± 0.1	1.9 ± 0.3
8	4.3 ± 0.3	6.3 ± 2.0	1.1 ± 0.1	1.7 ± 0.3
9	1.9 ± 0.4	4.7 ± 0.5	1.0 ± 0.2	0.9 ± 0.1
10	3.0 ± 0.6	5.5 ± 3.4	1.1 ± 0.1	1.9 ± 0.3
11	5.8 ± 1.2	12.3 ± 2.3	1.3 ± 0.2	2.2 ± 0.5

[a] Values are mean percentages ± the standard error of the mean.

sites ($P < .05$). At most localities (9 of 11), mud from Barn Swallow nests contained more organic matter than samples from Cliff Swallow nests (Table 1).

The organic matter in Cliff Swallow nests was primarily seeds and other fine particulate matter, while that in the nests of Barn Swallows consisted of coarse items, such as grass stems, horse hair, and feathers.

TABLE 2

TEXTURAL COMPONENTS AND SAND SIZES IN MUD SAMPLES SELECTED FROM THE BASE AND RIM OF 5 CLIFF AND 7 BARN SWALLOW NESTS

	Cliff		Barn	
	Rim	Base	Rim	Base
Textural component				
Sand	61.4 ± 2.8[a]	62.4 ± 2.6	50.3 ± 1.7	48.7 ± 1.8
Silt	25.0 ± 1.2	25.9 ± 1.5	33.7 ± 1.4	35.4 ± 1.4[b]
Clay	13.6 ± 1.8	11.6 ± 1.1	16.1 ± 1.3	16.0 ± 0.8
Sand size				
Very coarse	18.5 ± 7.1	20.3 ± 5.8	31.0 ± 5.7	26.7 ± 4.5
Coarse	9.8 ± 2.4	10.4 ± 1.5	8.8 ± 1.4	8.9 ± 1.4
Medium	28.8 ± 2.7	30.3 ± 2.6	23.4 ± 1.4	24.1 ± 1.4
Fine	42.9 ± 8.7	39.0 ± 5.4	36.9 ± 5.3	40.3 ± 5.4[b]

[a] Values are mean percentages ± the standard error of the mean.
[b] Difference between rim and base samples is statistically significant at the 95% probability level.

Moisture content.—The mud samples from nests of both species contained very little water. The mean moisture content of the mud in Cliff Swallow nests was 1.9 ± 0.2%, while that in Barn Swallow nests was 1.8 ± 0.1% (Table 1). These interspecific differences are slight and are not statistically significant ($P > .05$), but the differences among sites are ($P < .05$). Locality differences were not correlated with nest placement, ambient humidity conditions, or the type of structure on which the nest was located.

Intra-nest differences.—Samples taken from specific regions of the nest (i.e., base and rim) were very similar in their textural components and in sand size (Table 2). Intra-nest differences in the percentage of silt and fine sand in Barn Swallow nests are statistically significant at the 95% probability level; all other intra-nest differences are not statistically significant ($P > .05$). Hence, for all practical purposes the mud in these nests can be considered to be homogeneous.

DISCUSSION

It is clear from the preceding analyses that the 2 species of swallows select different materials for the construction of their nests. The primary differences among the variables measured are in the texture of mud and the amount of organic matter used in the nest.

Cliff Swallows selected mud with a higher sand and lower silt content than that selected by Barn Swallows (Fig. 2). These differences are especially meaningful when one considers that both species presumably had access to the same mud source at each of the collecting sites. Emlen (1954) observed that Cliff Swallows may gather mud from sources 0.8 km or more from the nesting colony, that is, from distances twice the maximum distance separating nests of the 2 species at any of our collecting sites. Buss (1942) also found that Cliff Swallows would carry mud for nest building as far as 1.2 km.

Despite these interspecific differences, both species appeared to be using mud within a restricted range of texture. Ninety-five percent of the textural observations are within the bounds of 41–77% sand, 17–43% silt, and 4–28% clay. These textural ranges include sandy loam, sandy clay loam, and loam soil types. Interestingly, Buss (1942) suggested that loam, silt loam, and clay loam might make the best mud for nest-building.

The organic matter in the nests of the 2 species differed both in form and in quantity, the former being the more conspicuous difference. Less obvious were the differences in the amount of organic matter incorporated into the nest, which while seemingly slight are statistically significant.

Emlen (1954) noted that the quality of mud used by Cliff Swallows varied considerably from locality to locality. Such variation among sites is apparent in the specific parameters of texture, sand size, moisture content, and organic matter measured in this study. These differences might be expected to reflect differences in the temporal and geographic availability of particular mud (soil) types. However, the site differences described above cannot be correlated with any major geographic or geologic features that affect the distribution or abundance of soil types in western Montana. Based on analyses of differences among sites, there is no relationship between the major geographic area of the site and the values of any of the variables. For example, the mean sand content of mud samples from Cliff Swallow nests along the Blackfoot River (sites 5, 6, 7, 8) range from 52% to 66.2%, the lowest and next to the highest values for all localities.

The texture of the mud selected for nest-building by these species is undoubtedly influenced by many factors which are important in the design and construction of a mud nest. The most obvious of these are (1) how well the mud adheres to the supporting substrate (adhesion), (2) how well the particles in the mud hold together (cohesion), (3) how well the dried mud withstands compressive and tensile stresses (strength), (4) how easily the mud is manipulated during construction (workability), and (5) how resistant the mud is to changes in volume (shrinkage and swelling).

Interspecific differences in the texture of mud incorporated in the nest, especially where there are also obvious differences in nest shape, would suggest that some of the above factors may be more important than others in the construction of a nest with a particular design. To assess the importance of each of these factors and their relationship to nest design would require a detailed knowledge of the physical properties of the mud both in a plastic and nonplastic stage. Such information is currently unavailable. However, some insight into the importance of these factors in the selection of mud can be derived from the physical properties of adobe, other aggregate building materials (e.g., concrete and stucco), and soils.

In soils, the properties of adhesion and cohesion are most affected by moisture content, although texture is also of some importance (Baver et al. 1972). Cohesion increases with decreasing moisture content and is greater for clays (soils which are largely composed of small particles) than for other soils, while adhesion decreases with declining moisture content. At very low moisture contents, like those measured in the dried mud samples (1 to 6%), the increased cohesion is primarily due to a cementation effect between the dried particles (Baver et al. 1972). In view of the lack of significant interspecific differences in the moisture content of the mud samples and since the interspecific textural differences, although statistically significant, are rather minor compared with those differences in soils which substantially affect cohesion and adhesion, it would appear that the adhesiveness and cohesiveness of the muds selected by both species are similar.

The compressive and tensile breaking strengths of adobe and aggregate building materials are greatly affected by a number of factors, but most important are differences in texture and the inclusion of impurities (Eyre 1935, Mielenz 1965, Turneaure and Maurer 1908). Addition of sand to adobe reduces its compressive and tensile strength; the degree of reduction is directly proportional to the amount of sand added. When compared with "pure" adobe, adobe containing 75% sand (by weight) shows a 56% decline in compressive and a 50% decline in tensile strength, while addition of 25% sand only results in a 20% decline in compression and has no effect on tensile strength. Inclusion of organic matter (straw and manure) in adobe also decreases its strength, both in tension and compression (Eyre 1935). The actual reduction in strength resulting from inclusion of organic matter is largely dependent on the form of the organic matter and the amount added. However, the quantitative relationships between reduction in strength and form and the amount of organic matter is not clear (Eyre 1935). The increased sand content in the mud of Cliff Swallow nests effectively reduces its strength relative to that in Barn Swallow nests. Perhaps this reduction in strength accounts for the apparent "fragileness" of Cliff Swallow nests observed by Samuel (1971) and others.

Workability of aggregate mixtures (those containing sand or gravel) is a difficult factor to quantify, primarily because it is dependent on many factors. However, the texture or proportion of the mixture is very important (Mielenz 1965). In concrete and stucco an increased sand content improves the workability. Such "lean" mixtures are often used where strength and durability are not of major importance (Mielenz 1965). The higher sand content in the mud of Cliff Swallow nests would undoubtedly improve its workability, therefore facilitating the construction of a nest with a complex shape.

Volume changes in the dried mud may be brought about by changes in moisture content (during drying and afterwards) and temperature and are affected by texture (Eyre 1935). Adobe mixed with 50% sand (by weight) has coefficients of expansion and contraction that are ½ those of pure adobe (Eyre 1935). Addition of straw to adobe also reduces the coefficients of expansion and contraction, but only by about 15%. Because of their relatively high contents of organic matter and sand, and since most nests are sheltered from direct rain, volume changes in the mud are probably not great.

The differences in materials (texture of the mud and organic matter) used by the 2 species appear not to be fortuitous, but instead to be related to the factors important in the construction of mud nests and to the differences in the complexity of design. The mud selected by Cliff Swallows, with its high sand content, is more easily manipulated mechanically which assists in the building of a more complex nest. Improved workability of the mud, however, occurs at the expense of strength and perhaps cohesion, which may explain why Cliff Swallow nests are noticeably more "fragile."

The inclusion of conspicuous amounts of organic matter (grass, feathers, and hair) in the nest of Barn Swallows may improve its cohesive nature, in that pieces of mud are bound together, which may further explain why these nests appear more durable in comparison to those of Cliff Swallows. The retort-shaped design of Cliff Swallow nests probably prohibits the use of such large pieces of organic matter.

SUMMARY

There are statistically significant differences in the composition of the mud selected by Barn and Cliff swallows for nest building. Furthermore, these differences appear to be related to the complexity of nest design. Cliff Swallows select mud with a higher sand and lower silt content than that used by Barn Swallows. A high sand content, based on the physical properties of other composite mixtures, probably improves the ease with which the mud may be manipulated and shaped into a retort-shaped nest. However, this increased workability of the mud is accompanied by a reduction in strength.

There are also statistically significant differences in the amount and form of organic matter incorporated in the mud of these nests. Mud from Cliff Swallow nests contains small amounts of seeds and other fine particulate matter, while that from the nests of Barn Swallows contains large amounts of coarse items, such as grass stems, horse hair, and feathers. The design of Cliff Swallow nests probably precludes the inclusion of such bulky materials, which in Barn Swallow nests probably serve to bind together pieces of mud.

The type and character of the mud used by these species varied from locality to locality, but within relatively narrow limits. The factors affecting the construction and design of mud nests (e.g., adhesion, cohesion, etc.) may well place constraints on the type of mud which can be used.

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REQUESTS FOR ASSISTANCE

Mexican locality records.—A comprehensive bibliography and gazetter of localities concerning birds in Mexico is being prepared. We will include all papers dealing with Mexican birds and birds recorded in Mexico. Authors wishing to have material included should send reprints of their materials to Mario and Isabel Ramos, Bell Museum of Natural History, University of Minnesota, 10 Church St. SE, Minneapolis, MN 55455.

Artificial nest structure literature.—An international bibliography on the use of artificial nest structures for bird research and management is being compiled. All contributions will be acknowledged in publication. Please send reprints and title lists to Jeffrey B. Froke, National Audubon Society, Box 157, San Juan Capistrano, CA 92675.